NJCAT TECHNOLOGY VERIFICATION

ENVIRONMENTAL H_2O LTD.
October 2002

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1. Introduction

1.1 NJCAT Program

NJCAT is a not-for-profit corporation to promote in New Jersey the retention and growth of technology-based businesses in emerging fields such as environmental and energy technologies. NJCAT provides innovators with the regulatory, commercial, technological and financial assistance required to bring their ideas to market successfully. Specifically, NJCAT functions to:

- Advance policy strategies and regulatory mechanisms to promote technology commercialization
- Identify, evaluate, and recommend specific technologies for which the regulatory and commercialization process should be facilitated
- Facilitate funding and commercial relationships/alliances to bring new technologies to market and new business to the state, and
- Assist in the identification of markets and applications for commercialized technologies.

The technology verification program specifically encourages collaboration between vendors and users of technology. Through this program, teams of academic and business professionals are formed to implement a comprehensive evaluation of vendor specific performance claims. Thus, vendors have the competitive edge of an independent third party confirmation of claims.

NJCAT has developed and published Technical Guidance Documents containing a technology verification protocol that is consistent with the New Jersey Department of Environmental Protection (NJDEP) Technical Manual and the Interstate Technology and Regulatory Cooperation (ITRC) program technical and regulatory documents. This technology verification review is consistent with the NJCAT general verification protocol contained in the guidance documents.

Pursuant to N.J.S.A 13:1D-134 *et seq*. (Energy and Environmental Technology Verification Program) NJDEP and NJCAT have established a Performance Partnership Agreement (PPA) whereby NJCAT performs the technology verification review and NJDEP certifies the net beneficial environmental effect of the technology. In addition, NJDEP/NJCAT work in conjunction to develop expedited or more efficient timeframes for verified/certified technology.

The PPA also requires that:

- The NJDEP shall enter in reciprocal environmental technology agreements concerning the evaluation and verification protocols with the United States Environmental Protection Agency, other local required or national environmental agencies, entities or groups in other states and New Jersey for the purpose of encouraging and permitting the reciprocal acceptance of technology data and information concerning the evaluation and verification of energy and environmental technologies; and

- The NJDEP shall work closely with the State Treasurer to include in State bid specifications, as deemed appropriate by the State Treasurer, any technology verified under the energy and environmental technology verification program.

1.2 Technology Verification Report

In February, 2002 Environmental H2O, Ltd., 4011 S.E. International Way, Milwaukie, Oregon submitted a formal request for participation in the NJCAT Verification Program. Environmental H2O has offices in New Jersey at 5 Erlington Drive, Cinnaminson, 08077. The technology proposed for evaluation allows for groundwater decontamination by providing an in situ oxygen generation source to increase the dissolved oxygen content of the water. The request was accepted into the verification program after pre-screening by NJCAT staff in accordance with the technology assessment guidelines. An in-depth meeting was held with the vendor followed by several phone and e-mail exchanges to solicit relevant information and supporting materials and to refine the specific claims. This report details the evaluation based on the performance claims of the vendor, H2O Environmental, reports of independent consultants detailing results of field evaluations of the technology, patent literature provided by H2O Environmental and literature articles supporting some of the studies.

1.3 Technology Description

1.3.1 Technology Status: general description including elements of innovation/uniqueness/competitive advantage

The proposed technology enables dissolved oxygen in groundwater to increase by generating oxygen in situ. The enriching process is carried out using an electrolytic cell that is placed into a well. The total apparatus consists of a submersible pump, the electrolytic cell, and a low-flow section above the electrolytic cell. These are assembled in a vertical assembly one on top of the other and placed in the well below the water table. A control panel, which controls DC power to the electrolytic cell and the submersible pump, is connected to the unit and is located above ground. Contaminated groundwater is pumped through the electrolytic cell where some of the water is separated into oxygen and hydrogen. The gases and water then flow upwards through a low flow distribution section that is above the electrolytic cell. The oxygen that is generated in the cell is absorbed into the water and the oxygen-enriched water then mixes with the groundwater in the well area. The pumping action sets up a vertical circulation pattern which provides for the distribution of the oxygen enriched water and the surrounding groundwater.

The water with the higher dissolved oxygen resulting from the electrolytic generated oxygen changes the groundwater from an anaerobic to an aerobic condition. At the same time the oxidation-reduction potential of the groundwater system is increased. Under these conditions aerobic microorganisms are able to degrade the organic contaminants. Other reactive species such as hydroxyl ions can also be generated depending on the power supplied to the electrolytic cell and the contaminants present in the groundwater that is being pumped through the electrolytic cell. This allows for the degradation of contaminants such as BTEX, MTBE and other organics that are subject to degradation under aerobic conditions or subject to degradation by attack from reactive species such as hydroxyl ions in the presence of oxygen. The process is trademarked under the name ISO-GEN™.

ISO-GEN™ is an innovative and important new method in supplying dissolved oxygen to groundwater that is oxygen poor, thus enabling aerobic processes to go forward. It has low capital and operating costs, as it is incremental to placing wells that are required for groundwater treatment. It is more effective then air sparging as it provides concentrated oxygen at the point where it is needed and can most easily be absorbed into the groundwater.

The technology is being used on a number of sites, particularly in the western United States and is commercially available in a small commercial version suitable for gasoline stations and small industrial sites. A larger commercial version that can generate more oxygen is under final development.

1.3.2 Specific Applicability

ISO-GEN™ is applicable to sites whose groundwater is contaminated with aliphatic, olefinic and aromatic hydrocarbons that are subject to aerobic biodegradation and where the conditions are such that the groundwater is either anaerobic or where there is insufficient dissolved oxygen to support aerobic degradation. Typical contaminants include gasoline hydrocarbons, diesel fuel hydrocarbons, BETX and similar contaminants. Oxygenated compounds such as MTBE are degraded at enhanced rates by the oxygen and hydroxyl ions produced in the ISO-GEN™ process.

The unit is self-contained as described in 1.3.4 below. The electrolytic cell that generates the oxygen is operated, normally, for ten minutes of every hour. The submersible pump is operated for longer or continuously so that it provides continuous vertical circulation of the groundwater. This provides for distribution of the dissolved oxygen and other reactive ions, such as hydroxyl ions, into the groundwater surrounding the well. It also helps to prevent fouling of the electrolytic cell plates.

1.3.3 Range of Contaminant Characteristics

Dissolved hydrocarbons in concentrations up to several thousand ppb have been effectively treated. The only oxygenated contaminate reportedly treated to date is MTBE at concentrations up to 30,000 ppb.

1.3.4 Material Overview, Handling and Safety

No additional chemicals or biota are required. The unit is a self-contained assembly that is lowered into a well that has been drilled into the contaminated aquifer. The control unit is self-contained and converts AC electricity into the required DC current that is delivered to the electrolytic cell. The submersible pump also gets power through the control unit.

The hydrogen that is generated, which is not absorbed in the water, is captured in a trap at the top of the well or released to the atmosphere. It should not be of an explosive concentration, but proper precautions should be taken to use explosion-proof equipment and ensure that the area is free of spark generating equipment.

There appears to be no unusual handling, or safety issues other than the one stated above for the possible presence of hydrogen and the standard precautions when installing a well and handling electrically powered equipment.

1.4 Project Description.

The project included the evaluation of assembled reports on five site demonstrations and supplemental information provided by Environmental H2O Ltd.,

1.5 Key Contacts

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2. Evaluation of the Applicant

2.1 Corporate History

Environmental H2O Ltd. was formed in December 2000 as a joint venture to develop the markets for H2O Technologies Ltd. ISO-GEN™ product line. Environmental H2O Ltd. is a subsidiary of H2O Technologies Ltd, and is 100% owned by H2O Technologies Ltd.

2.2 Organization and Management

Environmental H2O Ltd. is a limited liability corporation with a Managing Directors, L. Donald Ochs. Its principal office is located at 4011 S.E. International Way, Milwaukie, OR 97111. Another office is located at 5 Erlington Drive, Cinnaminson, NJ 08077. Environmental H2O, Ltd. is incorporated in Delaware. An internal Board of Directors, all of whom are executives of H2O Technologies, Ltd., guides the corporation.

The parent company, H2O Technologies, Ltd. is incorporated in the State of Washington. It has executive offices located at 150 Randal Street, Oakville, Ontario, Canada L6J IP4. The management of H2O Technologies consists of David Sutherland Yoest, CEO, A. Douglas Hink, President and COO, and L. Donald Ochs.

2.3 Operating Experience with Respect to Proposed Technology

ISO-GEN^{TM} is operating or has operated at over 25 sites. Of these, 15 are active at this writing. Remedial activities have been completed at a number of the remaining sites. At some other remedial sites activities are expected to restart once the ISO-GEN^{TM} units are in place.

2.4 Patents

H2O Technologies, Ltd. holds two patents for the ISO-GEN^{TM} Process:

US 5,911,870, Housing and Method That Provide Extended Resident Time For Dissolving Generated Oxygen Into Water, June 15, 1999

US 6,332,972 B1, Decontamination Method And System, Such As An In Situ Groundwater Decontamination System, Producing Dissolved Oxygen And Reactive Initiators, December 25, 2001

2.5 Technical Resources, Staff and Capital Equipment

Environmental H2O Ltd. is located in a 5,000 sq. ft. office space in Milwaukie near Portland, OR. The space contains research, development and testing space as well as offices. There are three full time employees; eight field installation subcontractors provide field support. It also has a staff of approximately 15 employees of H2O Technologies Ltd. in the research and design areas. Manufacturing of all equipment is outsourced. There is mechanical and electrical design expertise within the company and its parent.

3. Treatment System Description

Degradation and mineralization of gasoline and diesel hydrocarbon fractions, as well as BETX, occurs most rapidly under aerobic conditions in the presence of suitable microorganisms. It also occurs rapidly if reactive initiators are present to extract hydrogen from the organic molecule leading to further molecular breakdown. Oxygenated organic molecules also can be degraded in the presence of the appropriate microorganisms under aerobic conditions (12,13,15). The ISO-GEN^{TM} process provides dissolved oxygen, as well as reactive initiators, in situ, resulting in more rapid degradation of the contaminants of concern (7,9).

The system consists of one or more vertical circulation wells of about 4 inches in diameter, which are strategically placed within the contaminated groundwater plume and within the vertical extant of the plume. The ISO-GEN^{TM} apparatus, consisting of a submersible pump, electrolytic cell and distribution chamber are lowered into the well with the intake of the submersible pump above the level of the bottom of the plume. The pump, cell and distribution chamber are connected and are vertically aligned. The pump takes groundwater from the bottom of the well, which is screened so that is open to the bottom of the groundwater plume, and pumps it through the electrolytic cell. Electricity (DC) passing between plates in the electrolytic cell breaks some of the water down into oxygen and hydrogen. These are in the gaseous state and rise upward together with the groundwater into the distribution cell.

The length of the distribution cell is established to provide sufficient residence time for the gaseous oxygen to be absorbed into the water. The hydrogen rises to the top of the well where it is captured in a filter cover. Reactive initiators, such as hydroxyl ions may also be formed in the electrolytic cell and will also be absorbed into the water (7,9). The water leaving the distribution cell is distributed to the groundwater plume and some recirculates to the bottom of the well. In the plume a vertical circulation pattern is established by the flow of water into and out of the well. This provides for distribution of the dissolved oxygen and reactive initiators into the contaminated plume (10). The presence of the oxygen and initiators along with the microorganisms that are present provide the appropriate conditions for rapid aerobic degradation. This technology requires that consortia of degrading microorganisms are present; without them the degradation will not take place as envisioned in this technology application. It should be noted that initiators are not necessary for many of the degradation reactions to occur.

Power is provided to the pump through the control panel that is part of the system. A rectifier is part of the control panel which provides DC current to the electrolytic cell plates. The control panel monitors the current drop across the plates and shuts down the DC current to the plates if plate fouling or a short circuit condition is detected. If this occurs, the controller continues to provide power to the pump to keep water circulating. This allows the plates that are shorted, which is usually the result of material depositing on the plates, to be cleared by the flowing water. Under normal conditions, the unit produces oxygen for 10 minutes of every hour, but water continues to be pumped through the unit to continue the vertical circulation pattern and to help keep the plates clean. The system is self-contained and requires no above ground storage or treatment of the water as the water never leaves the groundwater plume and thus never comes to the surface.

4. Technical Performance Claims

Claim 1 – Full-scale field demonstrations have shown that the process of electrolysis used for the ISO-GEN™ technology generates dissolved oxygen in groundwater aquifers both in the groundwater well where ISO-GEN™ units are operated and at wells within the hydraulic radius of influence of the ISO-GEN™ operating wells.

Claim 2 – Pilot and full-scale field demonstrations have shown that the radius of influence observed for an ISO-GEN™ technology application extends in all directions including upgradient of the application well.

Claim 3 – Pilot and full-scale field demonstrations have shown that ISO-GEN™ produces positive changes in oxidation-reduction potential (ORP) in aquifers.

Claim 4 – Methyl tertiary-butyl ether (MTBE) has been shown to be bioremediated in the presence of oxygen and the ORP conditions created by ISO-GEN™ in microbially competent aquifers.

Claim 5 – Gasoline range aliphatic hydrocarbons (TPHg), diesel range aliphatic hydrocarbons (TPHd), benzene, ethyl benzene, toluene and xylene (BETX) have been shown to be bioremediated in the presence of oxygen and ORP conditions created by ISO-GEN™ in microbially competent aquifers.

Claim 6 – ISO-GEN™ produces a series of reactions in which no significant pH changes are measured in pilot and full-scale field demonstrations.

5. Treatment System Performance

The ISO-GEN™ system has been tested in pilot and full-scale demonstrations in the field at over 25 sites. These demonstrations have been at sites with a wide variety of soil conditions and topography. The chemicals of concern have been petroleum based hydrocarbon fractions and oxygenated petroleum additives with particular attention to MTBE. The technology has been patented, as discussed above. This evaluation is based on field data presented for five sites. In four of the five cases the sites were pilots that were operated for demonstration purposes. The gas station site at Oregon City, OR is considered full-scale by the vendor. Work is still proceeding at the Chevron Fuel Terminal at Banta, CA site as this evaluation is taking place.

5.1 ISO-GEN™ Case Studies

The five case studies are presented in the order that they were provided by the vendor to show the various aspects of the technology in actual field operation.

Case Study 1 – Gas Station, Oregon City, OR (11)

This site is a residential property adjacent to and down-gradient from a retail gas station that was operated until 1989. The station's underground storage tank and gasoline contaminated soil were excavated in 1990. The site consists of weathered basalt that has created a cohesive clay layer overlying silty clay to a depth of 20 feet. The groundwater is semi-confined and flows eastward from the service station to the residential property at a 0.04 gradient. Groundwater depth varies between 3 and 10 feet below ground surface depending on the season.

An ISO- GEN™ unit was placed in a well on the residential property that had the highest benzene value (MW-13) on August 23, 2000. The unit was operated for about 100 days. The electrolytic cell operated 10 minutes per hour, 24 hours a day with 24 volts supplied to the cell. The submersible pump circulated groundwater across the cell and through the distributor on top of the cell and to the top of the water table. In order to monitor the operation two piezometers, P-1 and P-2, were dug 4 and 8 feet respectively down-gradient from the operating well (MW-13), A side-gradient well (MW-6) about 25 feet from the operating well was also used to monitor the operation.

During the two-year period prior to the demonstration of the ISO- GEN™ technology the highest benzene concentration in the groundwater at the service station was 1,000 ppb, in MW-6 and 960 ppb in MW-13, a well on the residential property. Maximum TPHg values at the same well locations were 4,850 ppb and 26,000 ppb for the service station and residential property respectively. The benzene concentrations just prior to the start of operations were 793 ppb and 5,390 ppb respectively in P-1 and P-2, 338 ppb in MW-6, the side gradient well, and 593 ppb in MW-13 the ISO-GEN™ operating well, as detailed in Table 1 below. Prior to the beginning of operations the dissolved oxygen (DO) was measured in MW-13, MW-6, P-1 and P-2 at concentrations of 1.16 ppm, 2.04 ppm, 2.10 ppm and 3.13 ppm respectively.

The groundwater in the operating well MW-13, as well as in well MW-6 (which had the high benzene reading) on the service station, and piezometers P-1 and P-2 was sampled monthly. Dissolved oxygen (DO), TPHg, benzene, toluene, ethyl benzene and total xylenes were the analytes of concern. The DO was measured in the field using a YSZI Model 55 DO meter; other analytes were sent to a laboratory for analysis.

Case Study 2 -Gas Station, San Luis Obispo, CA (16)

The site is an active gasoline station owned by Chevron Oil Company in the City of San Luis Obispo, California. The site surface is level and about 120 feet above mean sea level. Directly south and adjacent to the site is a creek that is 10 to 15 feet below the level of the gas station. Groundwater beneath the site is about 3 to 4 feet below ground surface on the northern portion of the property, dropping to 10 to 12 feet below ground surface on the southern portion of the property. The groundwater is unconfined to semi-confined in a predominately clayey to silty alluvial sediment with lesser amounts of sand. The groundwater flows toward the creek at a gradient of 0.01.

The primary chemical of concern is methyl tertiary-butyl ether (MTBE). The MTBE impacts soil in the capillary fringe and below the groundwater table south of the dispenser island that is located in the western part of the property about half way between the northern and southern property boundaries. Baseline MTBE concentrations varied between 17 ppb at the western edge of the property (MW-11) to 33,000 ppb just south of the dispenser island (MW-10). The site has 11 monitoring wells and two ISO-GEN™ operating wells. Seven of the monitoring wells were used as observation wells during the demonstration. The two operating wells are located south of the dispenser island but north of one of the hot spots (MW-6 with 22,000 ppb MTBE). The operating wells are 4-inch PVC monitoring wells.

The ISO-GEN™ demonstration was carried out between August 8, 2000 and January 16, 2001 with an interruption from October 30, 2000 to November 21, 2000 to conduct a high vacuum extraction test. Field parameters were evaluated on a weekly basis and samples for analysis were taken monthly from the operating wells and seven monitoring wells in order to monitor the concentration trends of the MTBE and evaluate in situ biodegradation. Del Mar Analytical Laboratory preformed the analytical work for SECOR the independent consultant who carried out the field work.

An independent laboratory study was carried out by CytoCulture Environmental Biotechnology on three samples taken 120 days into the demonstration to evaluate the presence and significance of MTBE degraders in the wells (14). Samples were also taken and analyzed for the presence of MTBE degrading bacterial and analyzed by Truesdail Laboratoreis. (16)

Case Study 3 – Chevron Fuel Terminal, San Jose, CA (1,8)

This demonstration was to assess the applicability of the ISO-GEN™ process technology to promote the destruction of petroleum hydrocarbons on the down-gradient portion of the site to contain migration of the plume off site and at the same time decrease the size of the plume. The principal chemical of concern is MTBE. Petroleum hydrocarbons (TPHg and TPHd), as well as benzene, which was found in the plume, were also of concern.

The site is a 10-acre operating fuel terminal consisting of bulk storage tanks, a pipeline terminal and truck loading facilities. The site slopes gently westward and is about 75 feet above mean sea level. It is underlain primarily by silt and clay to 5 to 15 feet below ground surface. This is underlain to depths of 20 to 30 feet below ground surface by coarse-grained poor to well graded sand containing up to 1 ½ inch gravel. This forms a channel which trends southeast to northwest. The channel is underlain by moderate to high plasticity clay to a depth of about 70 feet below ground surface. Groundwater is located at a depth of 15 to 20 feet below ground surface and flows in a west-northwest direction at an average gradient of 0.004.

The site has 70 monitoring and extraction wells. ISO-GEN™ was applied to five wells (A-3, A-10, A-19, E-6 and E-7) which are located within and surrounding the high concentration portion of the plume. The test was begun on January 4, 2000 and operated for 10 months. However, during April and May of 2000 (90 to 120 days into the test) the system was not operating consistently due to lack of routine pump inspection and maintenance.

In July, 2000 two arrays of 5 observation points were installed within 6 to 12 feet of operating wells E-7 and A-19 in the center of and to the west of the high concentration portion of the plume. The wells were placed in a cluster essentially down-gradient of the operating wells. Weekly field measurements were taken for the observation wells and after July 2000 quarterly samples were taken from the observation points and operating wells to monitor concentration trends and evaluate in situ biodegradation.

Case Study 4 – Conoco Products Terminal, Bozeman MT (17)

The Conoco Products Terminal is located in an industrial area of Bozeman, Montana and has a series of storage tanks, and a truck loading facility with ancillary piping and an office building. The chemicals of concern present in groundwater are gasoline constituents.

The near surface material is primarily alluvial deposits of poorly graded silty sand and gravel. The depth to groundwater ranges between 4 and 8 feet below ground surface and flows north under a 0.02 to 0.05 gradient.

The site has five groundwater monitoring wells, only two of which (M-1 and M-4) have petroleum constituents above regulatory levels. M-1 has the highest values with average values taken before the test of 2350 ppb TPH and 553 ppb BTEX.

An ISO-GEN^{TM} unit was installed in monitoring well M-1. Six monitoring wells were installed to monitor the test and were located at distances of 8 to 45 feet north, estimated to be down gradient of the operating well at depths of 13 to 14 feet below ground surface.

The ISO-GEN^{TM} unit was installed on August 28, 2000 and operated continuously from September 5, 2000 to January 25, 2001 or 150 days. Samples were taken quarterly and analyzed for VPH (BETX, MTBE, naphthalene and TPH), COD and BOD. Field parameters measured included dissolved oxygen and oxidation-reduction potential.

Case Study 5 – Chevron Fuel Terminal, Banta, CA (3,4,5,6)

The Chevron Banta Terminal is located in Banta, California and consists of nine fuel storage tanks, tank-truck loading facilities, underground and above ground piping, and an office. The tank farm is enclosed by a 3-foot berm for secondary containment. The site is underlain by the San Joaquin Groundwater Basin.

There have been four spills at the site between 1984 and November 1999, including gasoline, diesel and heating oil. The site is under Cleanup and Abatement Orders and a Monitoring and Reporting Program. There are 23 monitoring wells and 3 piezometers on the site of which one piezometer has been destroyed and one well is inaccessible. Four of the monitoring wells monitor the lower aquifer at 48 feet below ground surface. The other wells monitor the upper aquifer at depths of 25 to 30 feet below ground surface. Monitoring wells MW-28A through MW-32A are located along the northeast fence above, in-between, and below the two operating wells at about 20-foot intervals from the operating wells. Other monitoring wells are interspersed among and around the four operating wells that are south west of the fuel tank farm.

Six ISO-GEN^{TM} wells were installed the week of September 28, 2001. Two of these wells (TW-5 and TW-6) are located along the northeastern boundary, and north east of the tank farm to prevent the containment plume from leaving the site. Four operating wells (TW-1. TW-2, TW-3 and TW-4) are installed south west of the tank farm. The system is still in operation at the writing of this evaluation. It is expected to be operational for a total period of 2 years or until September of 2003.

5.2 Verification Procedures

Environmental H2O working with various clients and consultants has applied ISO-GEN^{TM} technology at over 25 sites. Most of these were pilot demonstrations. Only one study, detailing the work at the San Jose site, was published ("Contaminated Soil Sediment & Water" a non-peer reviewed journal of the Association for Environmental and Health Sciences). However, sufficient information exists to support verification of the claims submitted. It is important that US Patents have issued and that regulatory organizations have agreed to use of the technology. Further, the science of electrolytic separation of water into hydrogen and oxygen and the absorption of oxygen into water is well documented in the literature. The use of vertical recirculating wells is well understood and has been successfully demonstrated and modeled.

Claim 1 - Full-scale field demonstrations have shown that the process of electrolysis used for the ISO-GEN^{TM} technology generates dissolved oxygen in groundwater aquifers both in the groundwater well where the ISO-GEN^{TM} units are operated and at wells within the hydraulic radius of influence of the ISO-GEN^{TM} operating wells.

All of the case studies presented above validate this claim over the life of the tests conducted.

Case Study 1 – Oregon City

Dissolved oxygen (DO) increased in the ISO-GEN^{TM} well (MW-13) from about 1 ppm to 13 to 15 ppm over the operating period. The DO levels in the two down gradient monitoring piezometers, 4 and 8 feet distant from the operating well increased from baseline values of 2 ppm and 2.5 ppm respectively, to as high as 5 ppm. The reductions in benzene and Total Petroleum Hydrocarbons – gasoline (TPHg) - in the side gradient well, the treatment well and close in monitoring piezometers are detailed in Table 1 after 28 days of operation in the case of DO and 100 days of operation in the case of the pollutants of interest. The data indicate that DO was available in the groundwater within the radius of influence.

Table 1 DO & Pollutant Concentrations – Oregon City, OR Site

Analyte	Date in 2000	MW-13	MW-6	P-1	P-2
DO, ppm	8/23	1.16	2.04	2.10	3.13
DO, ppm	9/20	15.24	2.21	4.84	4.72
Benzene, ppb	8/23	593	338	793	5,390
Benzene, ppb	12/05	47.6	109	128	1,030
TPHg, ppm	8/23	7.2	1.2	370	647
TPHg, ppm	12/05	1.35	0.39	4.05	13.7

Case Study 2 – San Luis Obispo

Dissolved oxygen (DO) exhibited increases over the baseline value of about 1 ppm to values ranging from 5 ppm to 20 ppm in one of the operating wells (R-1) and values ranging from 5 ppm to 10 ppm in the second operating well (R-2). DO values in one down-gradient well which had moderate concentrations of MTBE ranged from an initial value of 5 ppm to as high as 10 ppm and as low as 1 ppm; this well, W-3 was located about 25 feet down-gradient from treatment well R-1. The DO values in the other two monitoring wells, both with high MTBE concentrations remained at low initial levels of about 0.5 throughout the test period. One of these wells, MW-9 was located approximately 30 feet side and down-gradient of treatment well R-1, and initially had 22,000 ppb of MTBE in the groundwater. The other, MW-10, with 33,000 ppb of MTBE in the groundwater, was located approximately 30 feet up-gradient of the treatment well. However MTBE was degraded in the groundwater around these wells, as discussed below, indicating dissolved oxygen was available for MTBE biodegradation.

Case Study 3 – San Jose

Dissolved oxygen (DO) concentrations prior to the test initiation were at a 1 to 1.5 ppm level. After the ISO- GEN™ units began operation the DO concentrations in the operating wells ranged from 5 to 10 ppm. The DO levels in the observation points down-gradient of two of the operating wells increased from the baseline levels to as high as 3.4 ppm at a distance of 12 feet from the operating well.

Case Study 4 – Bozeman

Baseline levels of dissolved oxygen (DO) were less than 1 ppm ranging from 0.06 ppm to 0.59 ppm in the operating well. While the ISO-GEN™ unit was operating, the DO level increased to an average of 3.4 ppm (with a range of 1.5 ppm to 6.5 ppm) in the operating well, as measured in the flow through the cell during well purging that was carried out at low flow rates. In situ, the values, measured with a DO probe placed in the operating well 1 to 2 feet below the water level, ranged from 7.7 to 24.7 ppm. The higher value most probably represents supersaturation. The higher values observed in situ are most probably representative of the concentrations exiting the electrolytic cell. The values measured in the flow cell are most probably representative of those found in the groundwater. The monitoring wells surrounding the ISO- GEN™ operating well did not exhibit increases in DO concentrations with one exception where there was an increase to 2 ppm after 108 days of operation. The data show that DO is present in both the operating cell and in the groundwater around the operating unit.

Case Study 5 – Banta

In situ, dissolved oxygen was measured in four wells that were each 20 feet from the ISO-GEN™ operating wells; one observation well was on each side of the operating wells (T-5 and T-6) along the fence line. The DO in the four observation wells increased from levels ranging from 1.5 to 2.5 ppm at the beginning of the operation to 4.4 to 7.7 ppm 180 days into the oxygenation operation using the ISO-GEN™ technology.

Claim 2 – Pilot and full-scale field demonstrations have shown that the radius of influence observed for an ISO-GEN™ technology application extends in all directions including up-gradient of the application well.

The five case studies presented validate the claim that the radius of influence of the ISO-GEN™ technology extends in many directions. One case study shows that the radius of influence extends up-gradient as well as side and down-gradient.

Case Study 1 – Oregon City

Data was evaluated from a monitoring well that is located about 25-foot side gradient from the active ISO-GEN™ well and two piezometers located 4 and 8 feet down gradient. Prior to the operation of the ISO-GEN™ unit DO was 1.2 ppm in the operating well and 2.1 ppm, 3.1 ppm and 2.0 ppm in the observation well and piezometers. After 28 days, the DO level was 15.2 ppm in the operating well, 2.2 ppm in the observation well and 4.9 ppm and 4.7 ppm in the two piezometers.

Case Study 2 – San Luis Obispo

Oxidation-reduction potential (ORP) is related to, among other factors, the availability of dissolved oxygen, with ORP increasing with the increase in DO. Oxidation-reduction potential was measured in a number of observation wells including one that was up gradient (MW-10), one well side gradient (MW-11) and two wells down gradient (W-3 and MW-9). Prior to start up of the ISO-GEN™ unit, the ORP values were –25mV for the operating well and 23 mV, -94mV,
-49 mV and –72 mV for observation wells W-3, MW-9, MW-10 and MW-11 respectively. After 80 days of ISO-GEN™ operation the ORP values had increased to 740 mV in the operating well and 523 mV, 527 mV, 286 mV and 532 mV in W-3, MW-9, MW-10 and MW-11 respectively.

Case Study 3 - San Jose

DO levels were measured in five observation wells in and around two of the operating wells (E-7 and A-19) as well as in the operating wells E-7 and A-19. The observation wells were placed 4, 8 and 12 feet down-gradient from each of the operating wells and at about 11 feet from the 8 foot well at 45 degrees to the right and left of the down-gradient direction. The DO concentration in well A-19 increased from the baseline level of about 1 ppm to 1.5 ppm to values ranging from 7 ppm to as high as 13 ppm in the period covering 260 to 400 days of operation. During the same period of time, DO in the observation wells increased from baseline values to as high as 3.4 ppm in the well that was 12-foot down-gradient. The other observation well values varied between 1 ppm at 4 feet down-gradient to about 2.8 ppm for the observation point to the right of down-gradient. The DO in the second operating well (E-7) varied between 6 ppm and 11 ppm while the ISO-GEN™ was in operation. The observation points around E-7 had DO levels between 0.2 ppm (for the point that is 4-foot down-gradient) to about 2.8 ppm for the observation point that was to the left of the operating well after 390 days of operation. Intermediate values for the observation points ranged between 1 ppm and 4 ppm DO over the period that observations were taken

. Case Study 4 – Bozeman

Five observation wells were placed down-gradient of the ISO-GEN™ operating well, as discussed above. Prior to start-up of the ISO-GEN™ unit, the operating well DO as measured in situ using a DO probe, was between 0 ppm and 3 ppm; the DO measured in the low flow cell while purging the wells was between 0 ppm and 1 ppm. ORP was –50mV. After 100 days of operation in situ ORP was 10 to 25 mV, while the DO measured in the low flow cell was 2.5 ppm and the ORP was in excess of 700 mV. The DO in two of the observation wells increased from 0.7 ppm and 0.2 ppm to 5 ppm and 2 ppm, respectively, after 100 days of operation. The other three observation wells showed increases from the initial DO value of 0 ppm to about 1 ppm and then trailed off but remained above the initial zero level. The ORP in the observation wells increased from values of about –200 mV to values of about 100 mV after 100 days of operation.

Case Study 5 – Banta

In situ dissolved oxygen was monitored in four observation wells that were each 20 feet from the ISO-GEN™ operating well along the fence line (T-5 and T-6). These observation wells were in line with the operating wells. The DO in the observation wells increased after 180 days of oxygenation, using ISO-GEN™ technology, to levels between 4.4 ppm and 4.7 ppm DO from initial levels between 1.5 ppm to 2.5 ppm

Claim 3 – Pilot and full-scale field demonstrations have shown that ISO-GEN™ produces positive changes in oxidation-reduction potential (ORP) in aquifers.

Two of the case studies presented validate this claim

Case Study 2 – San Luis Obispo

The oxidation-reduction potential (ORP) in the operating well increased from –25 to 740 mV as presented in detail in the discussion under Claim 2. The ORP in the observation wells increased from values ranging initially from –94 to 23 mV to 286 to 532 mV after 80 days of ISO-GEN™ operation.

Case Study 4 – Bozeman

The oxidation-reduction potential (ORP) in the ISO-GEN™ operating well increased from –50mV to 700-800 mV after 100 days of operation. During the same period the ORP in the observation wells increased from about –200 to about 100 mV.

Claim 4 – Methyl tertiary-butyl ether (MTBE) has been shown to be bioremediated in the presence of oxygen and the ORP conditions created by ISO-GEN™ in microbially competent aquifers.

Two case studies validate this claim.

Case Study 2 – San Luis Obispo

Table 2. MTBE Concentrations (ppb) - San Luis Obispo Site

Date/Location	R-1	W-3	MW-8	MW-9	MW-10
8/1/00 (initial)	6,000	3,600	69	22,000	33,000
10/30/00	4,500	2,900	65	16,000	19,000

The data from observation wells W-3, MW-9 and MW-10 that are at various down-gradient locations from the ISO-GEN™ operating well, R-1, show significant decreases in MTBE between the start of the test on August 8 (August 1 is the baseline point) and the end of the first test period on October 30, as detailed in Table 2. Laboratory analyses for heterotrophic plate counts showed that bacteria concentrations increased over the test period in the observation wells. The laboratory results showed that on October 30, 150 MTBE utilizing bacteria colony forming units per milliliter (CFU/ml) were present in well W-3. There was essentially no decrease in MTBE concentration in MW-8 as there was no large degrader community due to the low in situ MTBE concentration. The analysis done by Truesdail Laboratories showed MTBE degrader bacterial colony forming units at a non-detect level in MW-8 (16).

Case Study 3 – San Jose

The MTBE plume size decreased markedly over the 10 months of operation of the ISO-GEN™ technology. Significant portions of the site had concentrations of MTBE in the range of 20 to 200 ppb. There was a long narrow strip with concentrations in excess of 200 ppb. After 10 months of operation, the area of the plume having MTBE in excess of 200 ppm had been reduced by half and the area containing between 20 and 200 ppb was reduced to about one-quarter of the original area.

Claim 5 – Gasoline range aliphatic hydrocarbons (TPHg), diesel range aliphatic hydrocarbons (TPHd), benzene, ethyl benzene, toluene and xylene (BETX) have been shown to be bioremediated in the presence of oxygen and ORP conditions created by ISO-GEN™ in microbially competent aquifers.

Two case studies support the validation of this claim.

Case Study 1 – Oregon City

Table 3 - Total Gasoline Hydrocarbons (TPHg) and Benzene Concentrations – Oregon City Site

	TPHg - ppm		Benzene - ppb	
	8/23/00 – baseline	12/05/00	8/23/00 – baseline	12/05/00
MW-13 – Treatment Well	7.2	1.05	593	47.6
Piezometer – P-1	370	4.25	793	21.1
Piezometer P-2	647	13.7	5,390	1,030
MW-6 – Observation Well	1.27	0.39	338	109

The data presented in Table 3, from the treatment well, the observation well and the piezometers clearly show significant decreases in both Total Gasoline Hydrocarbons (TPHg) and benzene. Similar reductions were obtained for the other BETX constituents. Details of the well and piezometer locations are discussed in the Oregon City Case Study described above.

Case Study 4 – Bozeman

Table 4 – Total Petroleum Hydrocarbon (TPH) and BETX Concentrations – Bozeman Site

	TPH - ppb		BETX - ppb	
	Baseline (i) 8/8/00 & 9/5/00	Final(ii) 1/29-30/01	Baseline(i) 8/8/00 & 9/5/00	Final(ii) 1/29-30/01
M-1 Test well	2350	110	553	37.6
M-2 (up gradient)	25	<20	2.5	<1
M-4 (down-grad)	350	360	35.2	7.7
M-5 (cross grad)	37	<20	22	0.86
CPB - 1	2000	260	452	65.3
CPB-- 2	9100	2400	1531	117
CPB - 3	7600	2600	2052	603
CPB – 4	2800	1300	540	188
CPB – 5	9800	1200	578	160
CPB – 6	1200	320	277	47.3

(i) Average of two observations before operation of the ISO-GEN™ Unit began 9/5/00
(ii) Samples taken either day; ISO-GEN™ stopped operation on 1/25/01

The data for the 100-day test period, presented in Table 4, show that there are significant decreases in both Total Petroleum Hydrocarbon and BTEX as a result of the ISO-GEN™ technology application.

Claim 6 – ISO-GEN™ produces a series of reactions in which no significant pH changes are measured in pilot and full-scale field demonstrations.

Two Case Studies validate this claim.

Case Study 2 – San Luis Obispo

The groundwater in all wells monitored, including the treatment wells, tended to range from slightly basic, with a pH range of 7.4 to 8.2, at the beginning of the test, to slightly acid, but still close to neutral, with pH in the range of 6.3 to 6.8 at the end of testing.

Case Study 4 – Bozeman

The treatment well pH decreased from 7.8 to 7.6 over the 100-day test period. The observation wells furthest away from the treatment well were stable at 6.7 to 6.8 pH, while the groundwater in the three wells closest to the treatment well showed increased pH, from a pH of 6.6 at the beginning of the test to a pH of 7.5 to 7.8 at the end of the test. These values are well within the "neutral" range.

6. Technical Evaluation Analysis

6.1 Verification of Performance Claims

Based on the evaluation of the results obtained from the five field demonstrations there is sufficient data available to support H2O Environmental's Claims 1, 2, 3, 4, 5 and 6.

6.2 Limitations

ISO-GEN™ technology is best utilized for remediation where the groundwater is low in dissolved oxygen but where there are consortia of microbes that are present or can be developed to promote biodegradation. It is, therefore, applicable to contaminants that may be recalcitrant but amenable to aerobic biodegradation. It will not aid in the degradation of contaminates such as PCE, TCE or PCBs that can only be degraded under anaerobic conditions. However, bioremediation of daughter products such as DCE and vinyl chloride can be enhanced as they degrade under aerobic conditions. It is not applicable to remediation of free product. If the groundwater is already high in dissolved oxygen, ISO-GEN™ technology may not be a necessary technology.

ISO-GEN™ is an enabling technology that provides additional dissolved oxygen in situ to enhance the oxygen content of the water. In order for it to be effective it requires that the aquifer be microbially competent, that is, that appropriate microbes, bacteria, be present in sufficient concentrations to be able to utilize the oxygen and contaminants to degrade the chemicals of concern. The soil in which the unit operates must have sufficient hydraulic conductivity, either natural or provided by other means, so that the oxygenated water can spread from the operating well(s).

The technology is available in a small commercial version suitable for gasoline stations and small industrial sites. A larger commercial version that can generate more oxygen is under final development.

7. Net Environmental Benefit

The New Jersey Department of Environmental Protection (NJDEP) encourages the development of innovative environmental technologies (IET) and has established a performance partnership between their verification/certification process and NJCAT's third party independent technology verification program. NJDEP in the IET data and technology verification/certification process will work with any New Jersey based company that can demonstrate a net beneficial effect (NBE) irrespective of the operational status, class or stage of an IET. The NBE is calculated as a mass balance of the IET in terms of its inputs of raw materials, water and energy use and its outputs of air emissions, wastewater discharges and solid waste residues. Overall, the IET should demonstrate a significant reduction of the impacts to the environment when compared to baseline conditions for the same or equivalent inputs and outputs. The ISO-GEN™ technology is compared with two existing state-of-the-practice technologies that will remediate petroleum hydrocarbons and oxygenated petroleum additives. The technologies used in the comparison are air sparging and soil vapor extraction (AS/SVE).

In addition to the design parameters detailed in Table 5 the following assumptions were made in the comparison. Each technology is sized to operate over a two-year period. All wells for all three processes will have to be drilled. Trenching at each wellhead will require a small trenching rig or a horizontal drilling rig. Well installation will require 3 hours per well using a 400 hp drill rig. Trenching will require 2 hours per wellhead using a 10 hp shallow trenching digger. For purposes of comparison, varying size groundwater plumes have been assumed with a concentration of 10 ppm total petroleum hydrocarbons including 1.5 ppm of MTBE and 1 ppm of benzene.

Table 5 - Design Data for Remediation Technology Net Environmental Benefit Comparison

Remediation Technology	Site Size		
	50' x 75'	0.25 acre	0.5 acre
ISO-GEN™ (2 yr. Operation)	1 Controller 4 Downhole Units 4 Wells	3 Controllers 12 Downhole Units 10 Wells	6 Controllers 24 Downhole Units 24 Wells
Air Sparging/SVE (2 yr. Operation)	12 As/ 4 SVE Wells 1 – 5 hp Blower	36 AS/12 SVE Wells 1 – 10 hp Blower	72 As/24 SVE Wells 1 – 20 HP Blower

The information on power consumption shown in Table 6 for the three technologies clearly shows the NEB for the ISO-GEN™ technology. In addition, there is no power requirement for a carbon adsorption unit that would be required to remove the hydrocarbons from the air stream. Also there will be no requirement to regenerate carbon or dispose of it as a waste product, since with the new technology the hydrocarbons will be mineralized in situ.

Table 6 – Energy requirements for Installation and Operation of State-of the Practice and ISO-GEN™ Technologies (includes installation and operation).

Remediation Technology	Site Size		
	50' x 75'	0.25 acre	0.5 acre
ISO-GEN ™ (2 yrs. Operation)	21,180 KWh	63,540 KWh	127,080 KWh
Air Sparging/SVE (2 yrs. Operation)	80,430 KWH	175,320 KWH	350,640 KWh

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